CHAPTER 10

OPERATIONAL READINESS QUALIFICATION

This chapter describes the airworthiness qualification issues related to reliability; operational readiness/ availability; maintainability; durability; warranties; training and trainers; transportability; manpower and personnel integration (MANPRINT); logistics; battle damage assessment and repair; corrosion prevention and control; rationalization, standardization, and interoperability (RSI); ship-based operation compatibility; ground support equipment; tie-downs; and moorings.

10-0 LIST OF SYMBOLS

d	=	discrimination ratio = Π_2/Π_1, dimensionless
F_N	=	number of failures, dimensionless
f	=	inherent failure rate, failures/h
MCTF	=	mean cycles to failure, cycles
MRBS	=	mean rounds between stoppage, rounds
MTBF	=	mean time between failures, h
MTBUMA	=	mean time between unscheduled maintenance actions, h
MTTR	=	mean time to repair, h
OR	=	operational readiness, dimensionless
OT	=	operating time, h
ST	=	standby time, h
TALDT	=	total administrative and logistics delay time, h
TCM	=	total corrective maintenance downtime, h
TPM	=	total preventive maintenance downtime, h
TTR	=	time to repair, h
t	=	number of accumulated test life units, dimensionless
I	=	producer's risk, probability that equipment with *MTBF* = Π_2 will be rejected
ϑ	=	consumer's risk = probability that equipment with *MTBF* = Π_1 will be accepted
Π_1	=	lower test *MTBF*, h
Π_2	=	upper test *MTBF*, h

10-1 INTRODUCTION

Operational availability, or readiness, can be defined as the proportion of time that a system either is operating or is capable of operating when used in a specific manner in a typical maintenance and supply environment. All calendar time in a specific period is considered in the calculation of this proportion. Elements of this calendar time include operating time *OT*, standby time *ST*, total corrective maintenance downtime *TCM*, total preventive maintenance downtime *TPM*, and total administrative and logistics delay time *TALDT*. Operational readiness *OR* is defined as follows:

$$OR = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}, \text{ dimensionless} \quad (10\text{-}1)$$

The intent is to include all characteristics critical to field operations in the definition of operational readiness. Eq. 10-1 shows that operational readiness is improved primarily by reducing maintenance time and/or administrative delay times. Criteria objectives for measuring operational readiness and specific logistics functions should be based on obtaining the data necessary to establish the values of the variables in Eq. 10-1.

Airworthiness can be affected by the transition of a system from development to operational use, and care should be taken to ensure that any significant differences in readiness are identified early in the transition. During developmental testing, aviation systems are typically maintained by prime contractor personnel who have experience working with developmental systems. Prototype or developmental systems are limited in number; thus extensive company resources can be concentrated on maintenance and support of those systems. Additionally, developmental testing is generally conducted at fixed Government or contractor facilities without real exposure to field environments.

Once operational testing begins, contractor personnel supporting systems are replaced with typical operators and maintainers, usually personnel who have recently completed training on the systems. Operator and maintainer errors become more prevalent, environmental conditions vary, and logistics support is usually short of that enjoyed at contractor facilities.

As the systems complete operational testing and are fielded, the importance of these additional sources of *OR* detractors increases. The numbers of systems, locations of those systems, experience of operators and maintainers, and length of the logistic pipeline have significant airworthiness effects on the operation and maintenance of aviation systems in field environments.

10-2 RELIABILITY

Reliability requirements should be included in the request for proposals (RFPs) by specifying quantified reliability requirements and allowable uncertainties, failure definitions and thresholds, and life cycle conditions of use. Typically, these reliability performance requirements should be specified in the air vehicle specification. Also objective requirements for reliability predictions, reliability maintenance and support, and reliability testing can be included to support the assessment of risk in achieving quantitative reliability requirements and to support risk management efforts. The air vehicle contractor (AC) should be responsible for developing or selecting analysis and modeling tools. The RFPs should solicit adequate information to evaluate the source data, models, reasonableness of modeling assumptions, methods, results, risks, and uncertainties. The procuring activity (PA) should avoid citing by specification, standard, handbook, or language “how to” design, manufacture, or test for reliability.

The AC should determine the customer’s requirements and product needs. The AC, working with the PA and customer, should include the activities necessary to ensure that the customer’s requirements and product needs are fully understood and defined so that the detail design specification can be compiled. The AC should receive from the PA all available important usage and environmental condition information, such as how the product will be used, by whom, and where. The AC should make assumptions for use and environmental conditions not supplied by the customer and should make plans to verify these assumptions and measure or determine any unknowns. The AC should receive from the PA and customer a maintenance and servicing policy to consider during determination of reliability requirements. The AC should receive from the PA and customer product physical configurations and expected life time specification.

The AC should meet the customer's requirements and product needs. The AC should structure and follow a series of engineering activities that ensure the resulting product satisfies the customer's requirements and product needs with regard to product reliability.

The AC should adequately verify that the customer's requirements and product needs are met. The AC should include activities that assure the customer that the reliability requirements and product needs have been satisfied.

Failure definitions and life cycle conditions are necessary to define fully the quantitative reliability requirements. The extent to which failures and usage conditions are defined should be determined on an acquistion-specific basis.

Several types of reliability can be used. Inherent reliability includes only the effects of an item design and its application. The inherent reliability is often used during the design process to select optimum design components. Operational reliability includes the combined effects of design, quality, installation, environment, operation, maintenance, and repair and is used to predict or evaluate overall system performance in an operational environment. Mission reliability involves the probability of completing a specified mission profile or the mean life units between critical failures. Mission reliability is used to predict the ability of an item to perform its required functions for the duration of a specified mission profile. Flight reliability involves the probability that a flight-critical failure will not occur during a specified period of time. Flight reliability is often used to establish inspection criteria and time intervals for inspection, replacement, or other maintenance actions. General (maintenance significant) reliability involves the probability that a maintenance significant failure will not occur during a specified period or the probability the mean life units between a maintenance significant failure will be less than a given value. General reliability is often used to predict the maintenance man-hours and skill levels and logistics costs required to support a system.

The AC is totally responsible for the reliability of the air vehicle and for meeting performance requirements. The AC should be responsible for implementing methods such as failure reporting, analysis, and corrective action systems (FRACAS). The means to validate and demonstrate performance should be included as part of the contractor's integrated test plan. Useful information can be found in MIL-HDBK-781, *Reliability Testing for Engineering Development, Qualification, and Production*, (Ref. 1). Also, see MIL-STD-882, *System Safety Program Requirements*, (Ref. 2). System safety is one of the criticality denominators.

10-2.1 RELIABILITY MEASURES

Inherent failure rates (failures due to design or application) are normally expressed as failures during a predetermined number of life units. For flight hours failures would be expressed as failures per million flight hours. Thus inherent failure rate f and inherent mean time between failures $MTBF$ are related as follows:

$$MTBF = 1/f, \text{ h} \qquad (10\text{-}2)$$

Operational failure rates can be related to operational reliability parameters, such as mean time between unscheduled maintenance actions $MTBUMA$, mean rounds between stoppage *MRBS*, and mean cycles to failure *MCTF* in the same way.

Reliability estimates made on inherent failure rates are useful for planning purposes, for comparing alternatives, and for assessing proposed changes. When test and operational data become available, they are the basis for program decisions and actions and for revised reliability estimates. With appropriate adjustment, i.e., higher estimated failure rates to account for the operational environment stresses, inherent failure rates and *MTBF*s can be used to estimate operational failure rates and reliability.

10-2.2 FAILURE MODE, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

An analysis commonly used to develop source data for reliability is the failure mode, effects, and criticality analysis (FMECA). The FMECA documents probable failures in a system within specified ground rules, the effects of each failure on system operation, identification of single failure points, and ranking of each failure according to a severity classification or failure effect. The contractor should define the procedures that will be used to perform and document the FMECA. The failure identification and severity should be related to reliability measures, such as mission and flight reliability, i.e., a failure that is flight critical should be classified as more severe than one that may impact mission success. The FMECA is typically used by the contractor's reliability, maintainability, quality assurance, and other logistic engineers. Also it can be one of the sources used to determine flight safety parts. Relevant safety-related information can be found in MIL-STD-882, *System Safety Program Requirements*, (Ref. 2).

Although an FMECA may be important to the contractor's logistic support analysis process, the procuring activity might not require submittal of a formal report. It is recommended that an integrated product team be used to define the specific need and required format. If submittal of a formal report is required, it should be delivered in a format compatible with the computer system of the procuring agency. The analysis approach used for the FMECA may start at the highest indenture level and proceed through lower indenture levels (top-down) or at the part or assembly level and proceed through higher indenture levels (bottom-up). Both the bottom-up and top-down analysis methods are used to determine the effects of all postulated failure modes of the lower level components on the higher level component or system.

Each failure mode and item analyzed should have a severity classification assigned. Failures classified as Category I (catastrophic) or Category II (critical) are generally applicable to flight or mission reliability. All failures apply to other types of reliability cited in this paragraph. Since FMECA is a risk-reduction tool, the process is usually updated throughout the acquisition program to reflect additional data that become available. In this way, failure modes for items and interfaces should become progressively more defined through the time of qualification.

10-2.3 SAMPLE DATA COLLECTION

Three methods of data collection are used depending on the intensity of information required, objectives to be achieved, and cost. These methods include semicontrolled, controlled, and intensified data collection and are sometimes referred to as levels of data collection. All three data collection methods require the data collector(s) to record failure and repair data to a specified level depending on the requirement and use of the data. The Level

1 method, or semicontrolled, is the most economical and is used for low-intensity projects. Also, it is common for the maintainer of the equipment to act as data collector and record maintenance events and repairs. This method is best suited for fielded equipment that has completed the qualification process. The Level 2 method, controlled, is more expensive and is used for higher intensity projects. The Level 3 method, intensified, is the most expensive, detailed, and manpower-intensive method. Unbiased, test-dedicated data collectors must be trained in the use of the data collection system and in the maintenance of the equipment itself to be able to recognize tasks being performed by military or contractor maintenance personnel.

An agreed-upon methodology for reliability assessment is established before initiation of qualification tests. The test lengths necessary to demonstrate adequate reliability characteristics are statistically determined, and the required data elements are defined. Precautions should be taken to obtain unbiased data from the designated data collectors. Consideration should be given to equipment design, operating and maintaining personnel, and operating environments when test data are collected on equipment prototypes in the qualification process. Data collected on prototype designs may not provide valid representations of the fielded system if significant design changes are required. In addition, care should be taken when using data acquired from qualification units to ensure the stresses induced during the qualification tests do not adversely skew the reliability predictions due to premature failures caused by combined stresses not related to the anticipated usage spectrum. Proper confidence limits and statistical techniques are applied to estimate reliability in the fielded environment. These statistical techniques, including hypothesis testing and inference from reliability test data, are similar to those described in subpar. 10-2.5.2.

10-2.4 SCORING CONFERENCES

Scoring conferences might be used as a means to review and evaluate collected test and operational data to ensure the data are assembled into an accurate and manageable database for useful evaluation. The trend is toward the use of integrated product teams in a more continuous mode of evaluating developmental and operational test results. Also, in some cases, developmental and operational testing might be combined. The purposes of reliability, availability, and maintainability (RAM) scoring conferences are to establish a test database and to assure that a proper and consistent determination is made for categorizing (assigning classification and chargeability) test incidents against RAM requirements. Principal spokespersons are provided by the materiel developer proponent, the combat developer proponent, the operational evaluator, and the development evaluator. The development tester and the operational tester each provide a representative to scoring conferences who serves in an advisory role, and the logistician is invited as an observer. When requested by the materiel developer spokesperson, contractors may participate to provide insight into the cause of a failure.

Scoring conference results are reached by majority decision of the principal spokespersons. These results include classification and chargeability of each RAM incident in the test database based on the approved failure definition/scoring criteria (FD/SC) and on the applicable minority (dissenting) opinions for each RAM incident.

10-2.5 RELIABILITY TESTING

As stated in par. 10-2, the PA should avoid citing by specification, standard, handbook, or language “how to” test for reliability; however, validation of environmental performance might still be specified. The fundamental purposes of reliability testing should be to demonstrate compliance with performance requirements and to improve the product. The three objectives of reliability testing are typically to disclose deficiencies in item design, material, and workmanship; provide measured reliability data; and determine compliance with quantitative reliability requirements. Four types of reliability tests are included in two categories. Environmental stress screening (ESS) and reliability growth test (RGT) are reliability engineering tests performed during the development and qualification phase and are designed to identify deficiencies and cause correction in the design process; these tests should be emphasized. Reliability qualification tests (RQT) and production reliability acceptance tests (PRAT) are reliability accounting tests and, given the emphasis on RGT and ESS, are limited to those necessary to provide reliability data and determine compliance with reliability requirements. Tasks associated with reliability engineering and accounting tests should be tailored based on program complexity, needs, and cost and should include only those tasks that provide maximum return on cost and schedule investment. Although experience plays a primary role in task selection, it should be supplemented by analysis and investigation.

The reliability test program typically includes establishing a failure reporting, analysis, and corrective action system (FRACAS); developing or selecting analysis and modeling tools; and defining the equipment to be tested and the number of items to be tested. Test conditions, duty cycles, and environmental, operational, and performance profiles should be defined prior to the start of the reliability testing program.

For ESS MIL-STD-810, *Environmental Test Methods and Engineering Guidelines*, (Ref. 3) describes the guidelines used to conduct environmental engineering tasks and test methods to determine the effects of natural and induced environments on air vehicles. Environmental testing is conducted to assure that military equipment is designed and tested for resistance to the environmental stresses it will encounter during its life. Environmental stress screening procedures are designed to be implemented so that early failures due to weak parts, workman defects, and other nonconformance anomalies can be identified and removed from the equipment. Also MIL-STD-810 (Ref. 3) provides test methods recommended to duplicate numerous types of environmental stresses, both natural and induced environments. During ESS and early in RGT overstress conditions may be applied to identify deficiencies. However, the final portions of RGT and all of the RQT and PRAT programs should use environmental conditions that simulate the operational environment as closely as possible.

RGT and RQT are discussed in subpars. 10-2.5.1 and 10-2.5.2, respectively.

10-2.5.1 Reliability Growth Test (RGT)

As defined by MIL-HDBK-189, *Reliability Growth Management,* (Ref. 4), reliability growth is the positive improvement in a reliability parameter over a period of time due to changes in product design or the manufacturing process. RGT is conducted to enhance system reliability through the identification, analysis, and correction of failures and verification of the effectiveness of the corrective action. MIL-HDBK-781 (Ref. 1) describes the elements of RGT. Typical application of RGT begins with prototype articles, continues through early production articles, and terminates upon demonstration that the reliability requirements of the system have been met.

MIL-HDBK-189 (Ref. 4) describes three essential elements needed to achieve reliability growth. These elements are detection of failure sources, problem identification and feedback, and redesign effort based on the identified problems. Problem correction may be a continuous process, or corrections may be held in abeyance and applied as “block” corrections. Each method of correction provides different reliability growth predictions as shown in Fig. 10-1.

Whatever method of correction is used, *MTBF* calculations are performed by dividing the number of accumulated test life units *t* by the accumulated failures. Section 4 of MIL-HDBK-781(Ref. 1) describes the two evaluation methods, Duane and AMSAA, used to evaluate confidence intervals, goodness of fit, and point estimates of *MTBF*.

Growth testing should emphasize performance monitoring, failure detection, failure analysis, and incorporation and verification of design corrections to prevent recurrence of failures. To enhance mission reliability, corrective action should be focused on mission-critical failure modes, and to enhance basic or inherent reliability, corrective action should be focused on the most frequent failure modes regardless of their mission criticality. These efforts should be balanced to meet predicted growth for both parameters.

10-2.5.2 Reliability Qualification Test (RQT)

The purpose of RQT is to demonstrate that the equipment design conforms to specified performance and reliability requirements under the specified combined environmental conditions. RQT testing is normally conducted on equipment that is representative of the approved production configuration and should be conducted in accordance with the reliability test procedures approved by the procuring activity. Depending on the qualification technique used, RQT is continued until an accept or reject decision has been reached or the total required test time has been completed.

For components or systems that have not been qualified, four types of tests can be used to demonstrate contract compliance with accept-reject criteria. These four types of tests are the probability ratio sequential test (PRST), both regular and short run (high risk); the fixed duration test; and the all-equipment reliability test. All are based on the assumption that the underlying distribution of times to failure is exponential. Guidelines and procedures for application of each test may be found in Section 4 of MIL-HDBK-781 (Ref. 1). RQT test planning should be based on the requirements established by the PA and should include the development of a graphically portrayed reliability growth planning curve to indicate what the reliability value should be at various points in the development program if conformance to the reliability requirement is to be achieved. Planning and evaluation should be based on predefined failure definitions and verifications, failure reporting

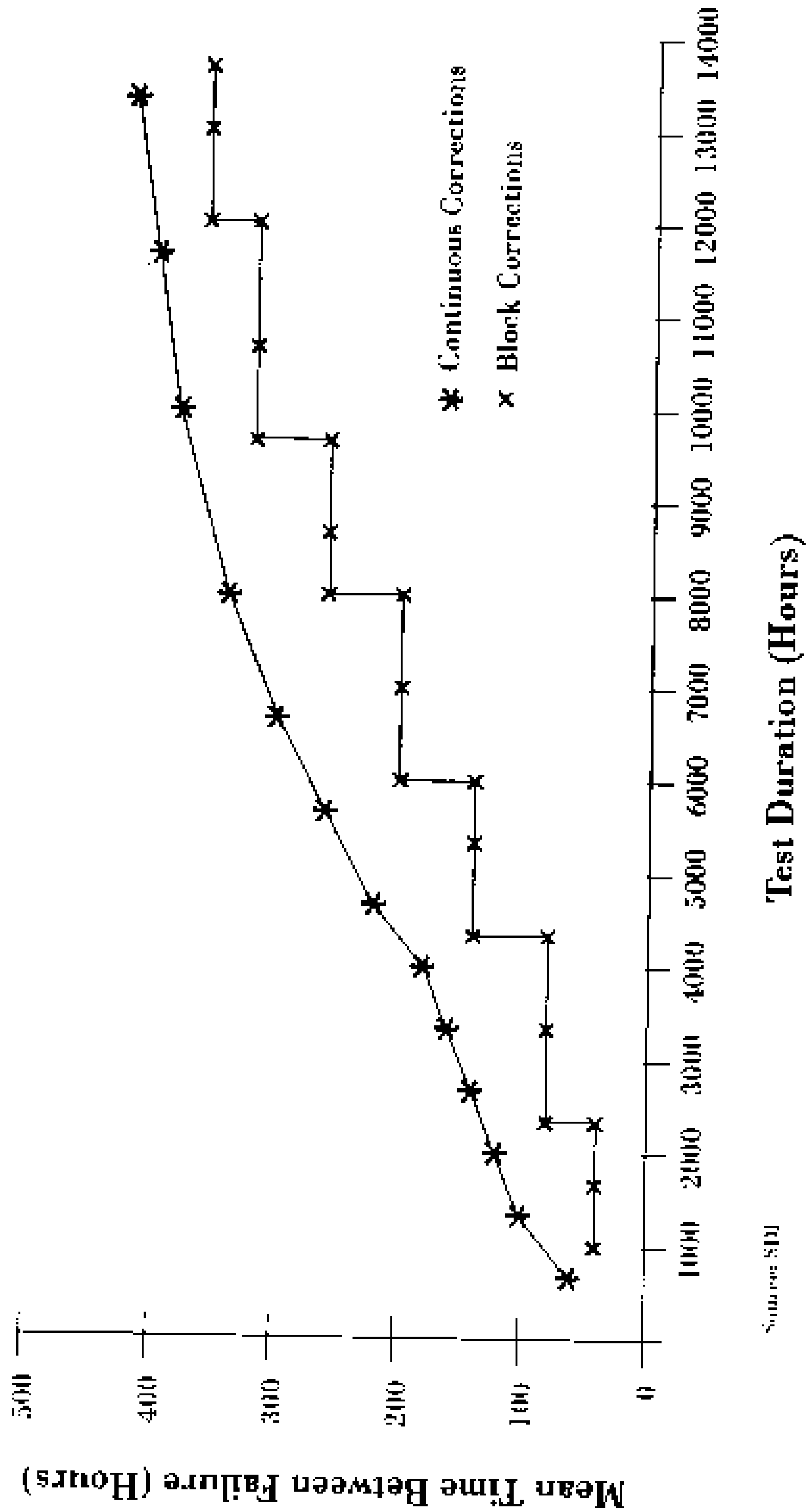


Figure 10-1 Typical Reliability Growth Test Results

procedures, and failure correction procedures.

The PA should specify lower test *MTBF* θ_1 and/or upper test *MTBF* θ_2. The ratio of upper to lower test *MTBF* is the discrimination ratio *d* and is a measure of the power of the test to reach a decision quickly. Higher values for *d* allow a quicker decision.

Acceptable decision risk also affects test planning and accumulated test hours. One type of decision risk is consumer's risk ß, the probability that equipment with *MTBF* equal to θ_1 will be accepted. Another type of decision risk is producer's risk α, the probability that equipment with *MTBF* equal to θ_2 will be rejected. Together with the discrimination ratio *d*, the tables of MIL-HDBK-781 (Ref. 1) relate to test duration (multiples of θ_1), *d*, α, ß, and acceptable and unacceptable numbers of failures for fixed duration test. This relationship is shown in Fig. 10-2. For fixed duration tests acceptable failures are equal to unacceptable failures minus one.

The same variables define the PRST accept-reject criteria. However, as shown in Fig. 10-3, acceptance or rejection is based upon the number of failures at a given test time falling outside the "Continue Test" range.

Each type of test—fixed duration versus PRST—has advantages and disadvantages, which are cited in Section 4 of MIL-HDBK-781 (Ref. 1).

10-2.5.3 System Endurance Tests

Endurance testing is conducted to demonstrate that the equipment has structural and functional life which is compatible with the system or subsystem life requirements. Endurance testing (sometimes called durability testing) may include a normal test, an overload (or overstress) test, and a mission profile cycling test, which duplicates or approximates the conditions expected during service. Requirements for endurance testing, correction and retest of failures occurring during endurance testing, requirements for failure reporting and corrective action system reporting, and passing criteria should be as specified by the PA.

10-3 OPERATIONAL READINESS/AVAILABILITY

Eq. 10-1 defines operational readiness *OR* as

$$OR = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}, \quad \text{dimensionless} \qquad (10\text{-}1)$$

Operational readiness and operational availability are generally used interchangeably and are used to describe the expected percentage of total time a piece of equipment can be expected to be available for use for its intended purpose. As can be seen from this relationship, detractors from operational readiness include total corrective maintenance downtime *TCM*, total preventive maintenance downtime *TPM*, and total administrative and logistic delay time *TALDT*. Analysis of operational readiness includes determination of the value of each variable in Eq. 10-1, the positive and negative effects of each variable (or characteristic), and the areas where improvement can most likely occur.

Reliability characteristics of a system—mean time between failure and mean time between unscheduled maintenance actions—affect operational readiness because each event—failure or

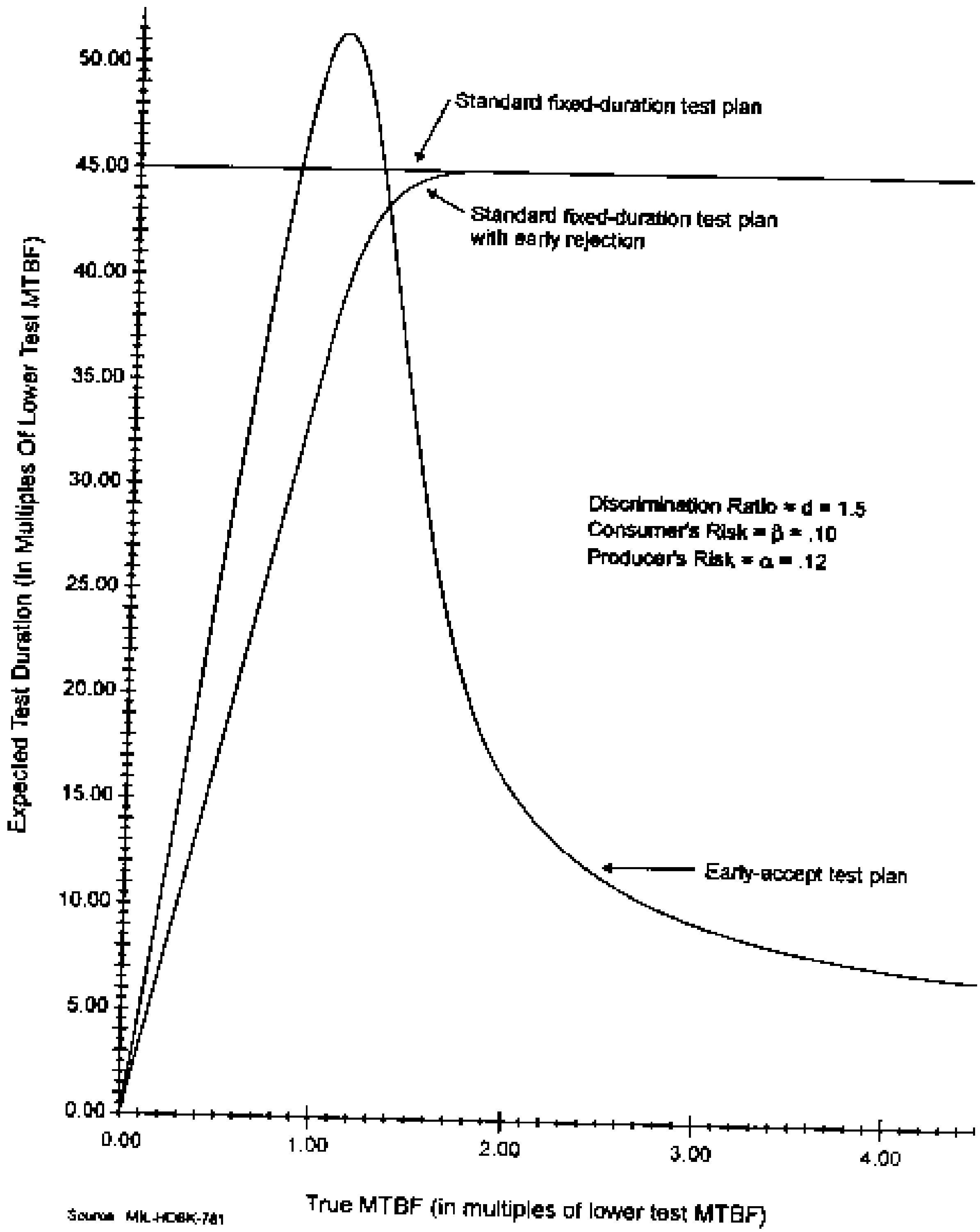


Figure 10-2 Typical Fixed Duration Reliability Test Plan

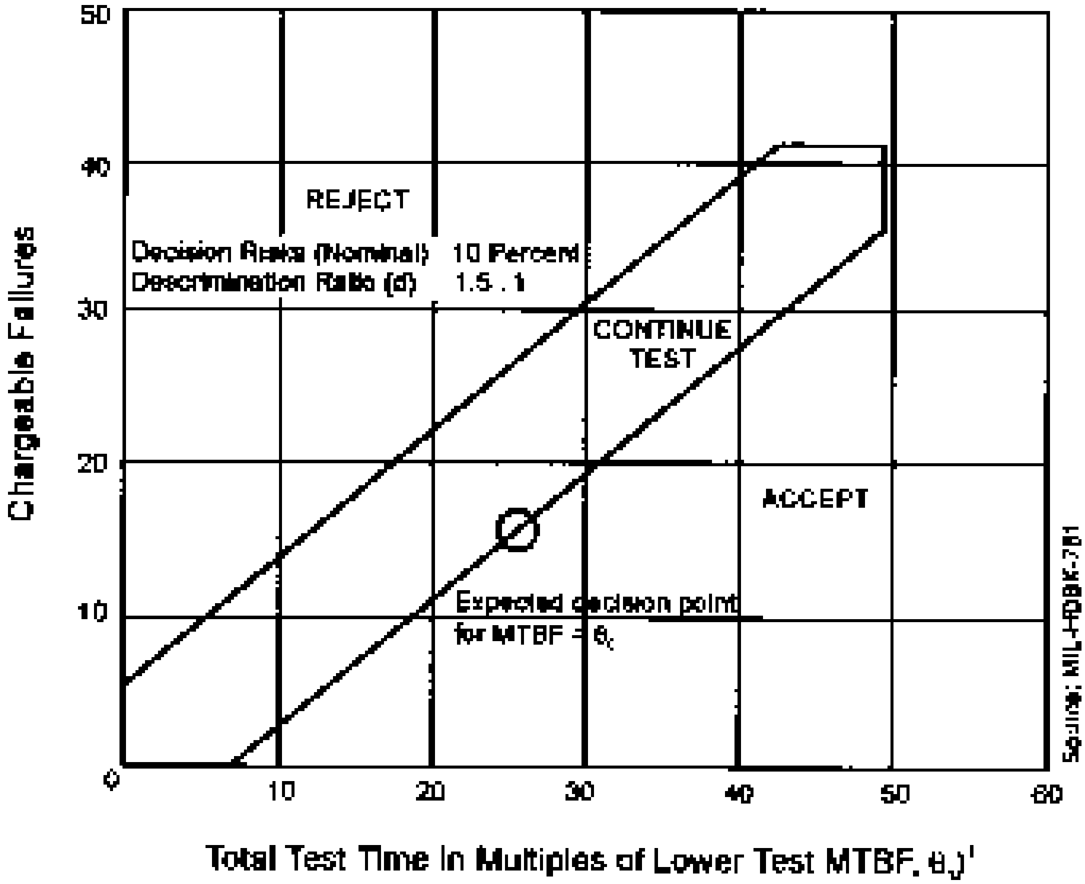


Figure 10-3 Typical Probability Ratio Seqential Test Plan

unscheduled maintenance action (UMA)—has an associated time to repair *TTR* and total administrative and logistic delay time *TALDT*. This effect is evidenced in the proportion of *TCM*. Maintainability characteristics are reflected in both *TCM* and *TPM* by the *TTR* and time to complete scheduled maintenance inspections. Logistic (principally supply support) characteristics are reflected in *TALDT* due to delays in obtaining spare and repair parts but may include delays in obtaining test equipment and/or tools.

Reduction of the proportion of *TCM*, *TPM*, and *TALDT* to total calendar time is essential to maintaining high *OR*. Therefore, the objectives of operational readiness qualification are to demonstrate that reliability (*MTBF* and *MTBUMA*), maintainability (mean time to repair (*MTTR*) and scheduled inspection downtime), and logistics parameters (*TALDT*) are sufficient to allow required operational readiness of the system. These reliability, maintainability, and logistics factors should be demonstrated to the specified levels of confidence.

10-4 MAINTAINABILITY

Maintainability is a characteristic of equipment that is expressed as the probability an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources. Achievement of the required level of maintainability should be demonstrated in accordance with the prime contractor's approved maintainability plan.

The PA provides the prime contractor with the operational information necessary to establish the maintenance and support concept. This information also provides the basis of the quantitative maintainability requirements for the rotorcraft or aircraft. This information includes but is not limited to

1. Operating hours per unit calendar time
2. Operational readiness and mission success objectives
3. Downtime or availability constraints
4. Mobility requirements
5. Self-sufficiency constraints
6. Manpower, skill, and support constraints
7. Reaction time requirements
8. Operational environment
9. Number and location of operational sites
10. Number of operational systems per site
11. Deployment schedule.

The individual elements of maintainability are evaluated to determine which detract from operational readiness.

Two such elements are ease of disassembly and ease of assembly. For repair actions involving disassembly and reassembly, these two elements usually comprise the main portions of time to repair *TTR*. Given appropriately trained personnel with sufficient skill levels, if disassembly or reassembly is difficult or prone to maintenance error, corrective maintenance time (CMT) will be excessive.

Mean time to repair is also another important element of maintainability. The *MTTR* is defined as the elapsed clock times to repair specific classes of deficiencies divided by the number of deficiencies. Difficult, time-consuming repairs that are frequently required will drive MTTR to excessive values. Assuming that no corrective actions are concurrent, *MTTR* can be used to determine *TCM* indirectly according to the following relationship:

$$TCM = \frac{OT * MTTR}{MTBF} = F_N * MTTR, \text{ h} \quad (10\text{-}3)$$

where

F_N = number of failures, dimensionless.

Improperly trained personnel or personnel with skill levels that are too low will also increase *MTTR* and thus *TCM*. Therefore, *MTTR*, skills, and training levels of personnel are maintainability elements that should be evaluated for aviation systems.

The maintenance level—unit, direct support (DS), general support (GS), or depot—responsible for each repair action should also be evaluated. Actions that are incorrectly designated as unit maintenance but require higher skill levels or additional support equipment not available in an organization increase *MTTR*, and there is a corresponding increase in *TCM*. Maintenance levels for PA-selected repair actions are evaluated as part of the contractor's maintainability program.

Inadequate support equipment used to detect, isolate, and/or diagnose faults also affect *MTTR*. Detection of faults that have not occurred (“false alarms”) increases the maintenance burden on the units. Failure to detect faults that exist can have airworthiness impacts since a problem has occurred but has not been identified by onboard detection and diagnostic equipment. Isolation or diagnosis to an ambiguity group (one of several components) increases repair times over the *TTR* for faults isolated to one component. Requirements for fault detection, isolation, and diagnosis are established by the PA, and the effectiveness of onboard and off-system diagnostic equipment and suitcase testers (portable test sets) should be evaluated using a PA-approved maintenance task sampling plan. Relevant information can be found in MIL-HDBK-471, *Maintainability Demonstration*, (Ref. 5). Faults or simulated faults are inserted into the system during the maintainability demonstration to determine whether the test equipment, maintenance procedures, and maintainer training are adequate to detect, isolate, and repair the fault properly. A failure mode and effects analysis (FMEA) should be applied to the functional level at which maintenance is to be performed to determine the failure modes or faults (open, short, etc.) that result in occurrence of the maintenance task of interest. Diagnostic procedures, test equipment, and repair procedures should be demonstrated by military personnel to confirm the adequacy of procedures, equipment, and training to achieve the contractual maintainability requirements.

Evaluation of maintainability elements is performed via statistical analysis of collected data. Relevant information can be found in MIL-HDBK-470, *Maintainability Program for Systems and Equipment*, (Ref. 6).

Maintainability testing should be conducted under conditions that are as realistic as possible to the anticipated environment and conditions for the system under test. This should include the presence of spares, tools, test and support equipment, technical publications, and personnel as anticipated for fielding. Fault insertions and simulated failures should be as realistic as possible but should not be used when the normal procedures could result in extensive damage to the equipment being tested.

10-4.1 PHYSICAL TEARDOWN AND MAINTAINABILITY DEMONSTRATION

Prior to fabrication of airworthy prototypes, mock-ups can provide a means to evaluate the accessibility of components for inspection and maintenance. Physical teardown of repairable components can also provide valuable maintainability information. Computer-aided engineering (CAE) substitutes are replacing inert physical mock-ups. Virtual prototypes are capable of a degree of functional realism that is comparable to a physical mock-up. Major subsystem components, wiring, cables, tubing, piping, and structural members should be mocked up to demonstrate accessibility. Electronic mock-ups should allow three-dimensional analysis for physical size, access, and clearances. Necessary changes identified during this analysis should be incorporated into the production configuration.

Physical teardown should be performed by the contractor using customer-defined facilities, tools, publications, and parts. The results of this physical teardown should be compared to predicted values, and corrective actions for design, procedures, tools, or parts are implemented as required by the PA.

10-4.2 TECHNICAL MANUAL VALIDATION

Technical manuals should be validated for technical adequacy and accuracy of repair parts and illustrated parts breakdowns; scheduled and unscheduled maintenance requirements; servicing requirements; troubleshooting; suitability of recommended tools; test, measurement, and diagnostic equipment (TMDE); and associated skill requirements. Typically, a tabletop review is accomplished on items such as checklists, schematics, wiring data, descriptive data, indexes, operational theory, basic issue items list, expendable supplies and materials, and the correlation of the maintenance manuals and the repair parts and tool lists. Hard copy maintenance manuals are validated for tasks selected by the PA. This selection might involve all maintenance tasks at each maintenance level. These evaluations are performed using typical user personnel.

If a video disk or onboard diagnostics will be used for the system, the same type of validation applies. Also ease of use, reliability of the system under field conditions, and ease of update should be evaluated.

10-4.3 TESTABILITY

When effectiveness of built-in test (BIT) and external test systems is required, testability attributes should be demonstrated and evaluated. Typical measures include fault detection accuracy, fault isolation accuracy, ambiguity level, and false alarm rates at each maintenance level. Also, typical procedures for these demonstrations are included in the addendum to MIL-HDBK-471 (Ref. 5).

10-5 DURABILITY

Durability can be defined as the probability that an item will successfully survive to its projected life, overhaul point, or rebuild point without a durability failure. A durability failure is a malfunction that precludes further operation of the item and is great enough in cost, safety, or time to preclude restoration, so the item must be replaced or rebuilt. Durability performance requirements should be specified in the air vehicle specification.

Typical measures include part life at replacement, time between overhauls (TBO), shelf life, resistance to corrosion, mean time between critical failures (MTBCF), and mean cycles to failure (MCTF). These data should be used to assess the achievement of contractual durability requirements, under both the basic climatic conditions and the extreme climatic conditions cited in the operational mode summary/mission profile (OMS/MP). Additional uses include evaluation of the planned supply support system and logistics-related durability factors.

Durability testing typically consists of a normal test, an overload test, and a mission profile cycling test, which duplicates or approximates the conditions expected in service. An integrated test program usually combines reliability and durability testing. Failures are evaluated, and corrective actions are incorporated into test items. If required by the PA, this information is documented in the Failure Reporting Analysis and Corrective Action System. The test is repeated, or at the option of the PA, the test may be completed and an additional run conducted to demonstrate that problems have been corrected.

Results of both technical test (TT) and initial operational test and evaluation (IOT&E) provide sufficient data to ensure that, with a high confidence level, the system meets contractual durability requirements and to assess achievement of each durability requirement according to the OMS/MP and under field support conditions.

10-6 WARRANTY

A warranty is defined as a promise or affirmation given by a contractor to the purchaser regarding the nature, usefulness, or condition of the supplies or services furnished under the contract. Warranties are acquired in accordance with the statutory requirements of 10 USC 2403, *Major Weapon Systems: Contractor Guarantees*, (Ref. 7) and regulatory requirements of FAR 46, *Quality Assurance*, *Subpart 7, Warranties*, (Ref. 8) and DFAR 246, *Quality Assurance*, *Subpart 7, Warranties*, (Ref. 9). AR 700-139, *Army Warranty Program Concepts and Policies*, (Ref. 10) assigns responsibilities, states acquisition policies, defines information requirements, covers fielding and execution procedures, and prescribes methods of compliance.

10-6.1 GENERAL PERFORMANCE WARRANTY

The purpose of warranties is to provide cost-effective and comprehensive coverage against failures of Government-procured items. Warranty performance measures are generally based on the number of items that fail to conform to the required performance standard at the required duration and the overall cost of the warranty compared to the expected cost of repair without a warranty. Warranty tailoring protects the Government from the costs and frequency of systemic failures and enacts responsive remedies for failures of significant operational impact. General performance warranties frequently use two basic concepts: expected failures and failure free.

1. The expected failure concept is based on the knowledge that the Government procures materiel to the minimum needs; therefore, any design will include expected failures. The contract supplier should not be liable for failures that are expected but should be held liable for failures that exceed the expected. The benefit from this concept is the initial contract warranty is provided with little or no cost since the Government requires remedies only for excessive failures. Procurement items adaptable to this concept include items that use contractor depot or intermediate contract support for maintenance.

2. The failure-free concept requires a period of failure-free use. Commercial and trade practice warranties are examples of this concept. Since failures may occur, the cost of the warranty normally includes the expense of repair or replacement that can be expected during the warranty term. The failure-free warranty may also be used when the reliability of an item is unknown or unspecified, such as for a nondevelopmental item.

Prior to negotiated procurement of an item warranty, a cost-effectiveness analysis is required to determine the value of the potential benefits received in comparison to the contract cost of the warranty plus the cost to the Government for administration and execution. This analysis is used to determine the value of the benefits, such as reduced maintenance or materiel cost, in comparison to the cost to the Government plus any readiness-related cost. Additional float quantities required, equipment downtime, or other productive time lost attributable to the exercise of the warranty incurs readiness-related costs.

Assessments are performed for warranties on an in-process and final payoff basis. Warranty benefit may differ depending on the procurement strategy. Nondevelopmental items may be well suited to a warranty program if that is the normal procedure used by the manufacturer. On the other hand, warranties may not be appropriate for low-cost items designed for discard. Warranty assessments should be used to determine warranty provisions and tasks for follow-on procurements and competitive resupply of the item or a similar item; and the overall effectiveness of the item warranty. The assessments also provide guidance to qualifying competitive resupply items. Qualification of warranted items should consider the cost and impact to the system of a warranted item. Generally, items with warranties may not require a full qualification test, but this is probably not appropriate for flight-critical items.

10-6.2 RELIABILITY IMPROVEMENT WARRANTY

A reliability improvement warranty (RIW) is a contractual commitment that provides the contractor with a financial inducement to improve a system in order to reduce repair or replacement costs and thus enhance field operational reliability. In an RIW the contractor may increase profits by introducing engineering changes that cost effectively reduce repair or replacement costs. The requirements of an RIW usually include a guarantee of a specified reliability level, and the contractor is obliged to upgrade all existing units at the his expense if reliability falls below the specified level. RIWs are generally applicable to systems that can provide reasonable cost savings but do not increase risk of significant mission failures if the reliability improvements cannot be obtained. Reliability measurements and analysis are conducted as described in par. 10-2.

10-7 TRAINING AND TRAINERS

AR 350-1, *Army Training*, (Ref. 11) defines training devices and simulators as tools used to reinforce job performance and to conserve service resources. Trainers that faithfully replicate actual hardware functions, arrangements, environments, and procedures allow safe, effective habit transfer from trainer to air vehicle or support systems and thereby minimize hardware training time and operator or maintainer errors (Ref. 6). These devices also provide a cost-effective and efficient method of providing a capability to train and test the ability to detect, diagnose, and repair failures without risk of damaging the actual system and system hardware. Trainers allow the simulation of situations and conditions that may not be economically or safely trained in any other way. Such trainers include but are not limited to synthetic flight trainers (also called flight simulators), built-in trainers, intelligent trainers, and combat evaluation trainers. No safety or health hazards are permissible in accordance with AR 602-2, *Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process*, (Ref. 12).

10-7.1 TRAINING

Operators and maintainers are required to perform numerous tasks as part of their duties. However, some of these tasks are identified as critical. DA PAM 71-3, *Operational Testing and Evaluation Methodology, A Procedures Guide*, (Ref. 13) identifies the percentage of critical tasks demonstrated as a measure of performance (MOP) for training. Using validated procedures, the soldier should demonstrate, or attempt to demonstrate, all critical maintenance and operator tasks. Individual and unit training through the direct support and general support maintenance level, training materiel, devices, and other aids are addressed. Training tasks that can be accomplished in training devices include but are not limited to flight crew coordination and system procedural task training and individual maintenance procedural training, such as diagnostic, and remove and replace tasks.

RAM factors used to assess training devices and trainers, which include qualitative reliability requirements, scheduled availability, and maintainability factors, can be found in MIL-T-23991, *Training Devices, Military; General Specification for,* (Ref. 14). Other subjective measures are addressed in par. 10-9, "MANPRINT".

10-7.2 SYNTHETIC FLIGHT TRAINERS (FLIGHT SIMULATORS)

The percentage of critical operator tasks demonstrated is the accepted MOP. The primary purposes of synthetic flight trainers are to reduce cost through reduction of the required flight training hours and provision for a mechanism to train for emergency flight situations. Since the synthetic flight trainer is a simulation of actual flight, these trainers should be subjected to validation, verification, and accreditation (VV&A) mandated by Headquarters, Department of the Army (HQDA) policy. Through demonstration of synthetic flight trainer effectiveness in flight training, operator training effectiveness can be evaluated using fewer air vehicle and flight hours.

10-7.3 BUILT-IN TRAINER/TRAINING

A built-in trainer consists of auxiliary components added to an air vehicle or support system that allow the air vehicle to be used for training when not in use for operational or maintenance functions. The training is done via actual controls and displays to enhance the realism of the training scenario. Availability of appropriate built-in trainers involves the capability of air vehicles or support equipment to provide training to operators and maintainers during periods when maintenance or flight operations are not occurring. Using the air vehicle instead of cockpit procedure trainers eliminates the need for the cockpit procedure trainers. Also use of the actual air vehicle or support equipment ensures that layouts, functions, and procedures are identical to those for fielded systems. Availability of appropriate stimuli (e.g., simulated or actual threat warnings and responses, air vehicle systems information, and operator or maintainer actions) is critical to evaluation of the effectiveness of these trainers. Demonstrations of effectiveness for built-in trainers should include PA-required stimuli, systems responses, and operator or maintainer actions.

Trainer effectiveness should be demonstrated to show that the device is capable of replicating system functions, displays, and responses and should be tested to ensure the device is capable of being used to train the required tasks adequately. This type of demonstration and testing should be conducted by military users who are representative of the target audience intended to use the device. Trainer effectiveness of its intended function or functions is the primary prerequisite for qualification of the device for operational use.

10-7.4 INTELLIGENT TRAINERS

Artificial intelligence and expert systems used in trainers have primary goals of increasing the effectiveness of training and of reducing operator or maintainer workload. Expert systems may be as simple as automation of air vehicle maintenance troubleshooting charts or diagrams or as complex as using subject matter experts (SMEs) experiential data to identify the course of action with the greatest expectation of success. This success may be in the form of lowest number of man-hours or parts cost for maintenance or highest survivability in a combat or emergency situation. Artificial intelligence supplements expert systems by applying information that is not part of an experiential database in order to recommend a course of action.

Expert systems and artificial intelligence trainers should be subjected to VV&A by Government SMEs. Qualification of these devices includes determining that the device meets its requirements of performance and functionality. However, the device should also be assessed by the user to determine whether it can effectively be used to train its intended tasks adequately. Training effectiveness is generally measured by determining the level of competence of individuals after they have been trained on the device. These measures can include but are not limited to system knowledge, diagnostic capability, performance accuracy, and time required to perform a task.

10-7.5 COMBAT EVALUATION TRAINERS

Combat evaluation simulators are simulators or networks of simulators designed to replicate system performance of the simulated weapon system in a combat environment. These trainers are usually designed to replicate as closely as possible the capabilities of the system being trained as well as enemy and other friendly weapons systems. Combat evaluation systems can be used to predict or evaluate system effectiveness during development, and they can be used to evaluate unit effectiveness in employing the weapons system. In addition, these systems can be used to learn or develop new tactics, techniques, or procedures. Use of training devices for combat evaluation can overcome some of the obstacles to actual hardware evaluation. According to DA PAM 71-3 (Ref. 13), a major problem during the early stages of operational test and evaluation (OT&E) is insufficient available units to simulate the organizational relationships and interaction of the equipment with its operational environment. Data obtained during large force simulations can be used to extend test results and save considerable training resources and training costs. These trainers typically are used with other combined arms forces simulators (armor, artillery, etc.) to evaluate training.

Combat evaluation trainers should be subjected to VV&A by Government operational SMEs. Emphasis should be on verifying that critical unit mission performance replicates actual hardware performance capabilities and that constraints and limitations are identified.

10-8 TRANSPORTABILITY

The contract should provide minimal essential operational deployment information upon which specific transportability requirements are based. Specific requirements should be defined in the specification for the air vehicle. The AC should ensure that the systems, equipment, and munitions, including components and repair parts, are designed, engineered, and constructed so that required quantities can be moved efficiently by existing and planned transportation assets. Military Traffic Management Command (MTMC) requirements should be satisfied. All new air vehicles should be designed to be transportable in a given transport configuration and at a given weight that should be defined by the AC and approved by the PA. This needs to be accomplished early in the program. It should not be necessary to off-load fuel. Older air vehicles and nondevelopmental air vehicles typically have trouble satisfying transportability criteria. A load cap and some disassembly are often necessary. The US Army defers to the US Air Force in matters of air transportability. A detailed analysis should be performed to determine the specialized materials, tasks, tools, and equipment necessary to disassemble, transport, reassemble, and check out the air vehicle. The AC should define the means for packaging and tying down any assemblies and components that must be removed from the air vehicle to satisfy transportability criteria.

Information concerning development and shipment of materiel can be found in MIL-STD-1366, *Transportability Criteria*, (Ref. 15) and MTMCTEA Pamphlet 70-1, *Transportability for Better Strategic Mobility*, (Ref. 16). MIL-STD-1366 also covers dimensional and weight limitations for all modes of transport, slinging and tie-down provisions, containerization criteria, overloads, assembly and disassembly, air delivery, shelter criteria, and transportability testing. The transportation modes and the qualification criteria include but are not limited to the following:

1. *Self-Deployment (ferry flight).* For qualification the air vehicle should meet specified requirements for ferrying including the total distance to be ferried, length of the longest leg, and the equipment and personnel required to be carried with the air vehicle. Maximum range, including auxiliary fuel provisions and aerial refueling capabilities, should also be demonstrated.

2. *Aerial Transport*. MIL-STD-1791, *Designing for Internal Aerial Delivery in Fixed-Wing Aircraft*, (Ref. 17) provides general design and performance guidance for the transport of military equipment in Air Mobility Command (AMC) cargo aircraft and long-range international Civil Reserve Air Fleet (CRAF) aircraft. The contract should specify transportability requirements. The air vehicle specification should include the required dimensional envelope, weight and balance limitations, and tie-down limitations as needed in its transportable mode for each type of transport vehicle. Typically, these air vehicles might have 1/4 to 3/4 of a tank of fuel. The AC should define the maximum gross weight and level of disassembly at which the air vehicle satisfies static load criteria for transport. Maximum allowable time for preparation, packaging, and on-loading should be specified in the contract. Also the maximum allowable time for off-loading and reassembly should be specified. Time-trial demonstrations are typically required for qualification. The AC should provide the means for packaging and tying down of any assemblies that must be removed from the air vehicle for transport.

3. *Land Transport*. MIL-STD-209, *Slinging and Tie-Down Provisions for Lifting and Tying Down Military Equipment*, (Ref. 18) and MIL-STD-1366 (Ref. 15) provide relevant information for surface transportation; however, there are not really any defined load requirements for surface transport. Normally, US Army air vehicles are not transported by rail. Also the US Army does not allow highway transport of air vehicles on anything but air-ride trailers; no rough terrain transport is allowed. US Army air vehicles should be capable of being hoisted on and off the trailers. Slings, straps, tie-down fittings, etc., should be provided by the AC. Spreader bars are undesirable; however, if needed, they should be provided by the AC. Time-trial demonstrations for on-loading and off-loading are typically required for qualification. The AC should both define and provide the means by which to package and tie down any assemblies that must be removed from the air vehicle for transport. Highway limitations include the physical, legal, and administrative characteristics of roadways, bridges, and other structures. These limitations vary from state to state in the continental United States

(CONUS) as well as on outside CONUS (OCONUS) highway systems.

4. *Water Transport*. MIL-STD-209 (Ref. 18) and MIL-STD-1366 (Ref. 15) provide guidance for water transport also. Other than self-deployment, water transport is the primary means for movement of US Army air vehicles. Roll-on- and roll-off-type ships exist, but there are only a few of them. Air vehicles should be capable of being hoisted into and out of the holds of transport ships and barges. Slings, straps, tie-down fittings, etc., should be provided by the AC. Spreader bars are undesirable and typically are not allowed on some ships. Air vehicles take up space but are relatively lightweight and should be stored below deck, although not necessarily at the lowest level. Above-deck transport is generally not allowed. Contractual requirements for water transport should define the models of ships available, the size and location of areas available (typically belowdecks), transport operational constraints, and length of time onboard.

Considerations for all modes of transport also include the handling equipment, personnel, and time constraints necessary for any disassembly required to load and assembly after unloading the air vehicle.

The PA provides actual vehicles for demonstration when required. Demonstration of those items with critical clearance may be performed on the actual air vehicle or on a mutually agreed upon mock-up or simulation of the air vehicle. All demonstrations should be monitored by a representative of the PA. If a demonstration is unsuccessful, the contractor submits the corrective action. Final disposition and retest requirements are made by the PA.

10-9 MANPRINT

Manpower and Personnel Integration (MANPRINT) refers to the comprehensive management and technical effort necessary to ensure total system effectiveness by continuous integration of manpower, personnel, training, human factors engineering, system safety, soldier survivability, and health hazard considerations. Qualification criteria for these domains are addressed in AR 602-2 (Ref. 12), and the domains are described in the subparagraphs that follow. MIL-H-46855, *Human Engineering Requirements for Military Systems, Equipment, and Facilities*, (Ref. 19) establishes and defines the requirements for applying human engineering to the development of military systems. Information concerning the measurement of operator workload can be found in ADS-30, *Human Engineering Requirements for Measurement of Operator Workload*, (Ref. 20). The MANPRINT goals, constraints, and requirements stated in the materiel requirements documents are evaluated through MANPRINT assessments. These assessments aid in obtaining MANPRINT compliance by providing information upon which to make tradeoffs, such as quality and numbers of people, training, technology conditions, standards, costs, and personnel assignment policy.

10-9.1 MANPOWER

Manpower criteria include the human resource requirements and authorizations (spaces) needed for the operation, maintenance, and support of each system. Considerations necessary to establish these criteria include wartime workload data and the analysis of the tables of organization and equipment (TO&E), combat support (CS), and combat service support (CSS) requirements. Manpower requirements criteria (MARC) planning factors are based on providing minimum essential manpower position requirements.

10-9.2 PERSONNEL

Personnel criteria include the aptitudes, experience, and other human physical and mental characteristics needed by those who operate, maintain, and support each system. The skill levels and grades of the military and civilian persons required to operate and support the system in peacetime and wartime should be considered as part of the personnel MANPRINT criteria.

10-9.3 TRAINING

Training criteria include the instruction, time, and other resources necessary to impart the requisite knowledge, skills, and abilities in order to qualify personnel for operation, maintenance, and support of the system. Formulating the training for a new system requires analyses that address the expected aptitude levels, the nature and complexity of the knowledge and skills to be acquired, and the proficiency levels to be attained and sustained.

10-9.4 HUMAN FACTORS

Human factors engineering (HFE) criteria deal with the design of materiel to ensure that its use conforms to the capabilities and limitations of the fully equipped range of personnel that operate, maintain, supply, and transport the system in the operational environment. Considerations should include human characteristics, anthropometric data, system interface requirements, human performance, biomedical factors, safety factors, and work environments.

10-9.5 SYSTEM SAFETY

System safety criteria are used to determine attainment of the optimum degree of safety consistent with mission requirements (Ref. 2). It involves the identification, elimination, or management control of safety hazards. It also involves the identification, assessment (severity, probability, etc.), and resolution through elimination or reduction of associated risks to an acceptable level. It includes the risk management process throughout the life cycle. Specific safety operational readiness qualification requirements should be included in the Airworthiness Qualification Specification (AQS).

10-9.6 HEALTH HAZARDS

Health hazards criteria are developed by the application of biomedical knowledge and principles to identify, evaluate, and control risks to the health and effectiveness of personnel who test, use, maintain, and support the system. Considerations should include exposure to acoustical energy, biological substances, chemical substances, oxygen deficiency, psychological stresses, radiation energy, shock, temperature and humidity extremes, trauma, and vibration. Exposure criteria should be established in accordance with applicable standards and defined to the contractor by the PA. Health hazards should be identified and assessed as provided for in MIL-STD-882 (Ref. 1). Also see par. 9-17.

10-9.7 SOLDIER SURVIVABILITY

Soldier survivability, as defined by AR 602-2 (Ref. 12), is the characteristic of a system that can reduce fratricide as well as detectability of the soldier, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded, and reduce physical and mental fatigue. Damage, as used here, means injury or harm that impairs value or usefulness.

10-10 LOGISTICS

The contractor should be required to propose and describe the processes to be used to determine the logistic support required to keep the system usable for its intended purpose and the processes to influence the design so that the system and support can be provided at an affordable cost. The contractor's process should be evaluated and compared on a competitive basis. Typically, a logistic support analysis (LSA) process is used. Information concerning the LSA can be found in MIL-STD-1388/1, *Logistic Support Analysis*, (Ref. 21).

Usually, logistic support requirements are determined by an integrated analysis of all operator and maintenance functions and tasks to ascertain task frequencies, task times, personnel and skill requirements, supply support requirements, etc., including all elements of integrated logistic support (ILS). Optimization is achieved through allocation of functions and tasks to specific maintenance levels, repair versus discard analyses, reliability-centered maintenance (RCM) analysis, and formulating design recommendations to optimize maintenance times and logistic support resource requirements. Data from LSA usually are used as direct input into the development of data products associated with each ILS element, such as provisioning lists, personnel and training requirements, and technical manuals.

Whatever means is proposed by the contractor should be capable of providing data in a format compatible with the computer system used by the Government. The integrated product team has to define the required format. The general breakdown of a logistic support analysis record (LSAR) is as follows:

A. Operation and Maintenance Requirements

B. Item Reliability and Maintainability Characteristics

B1. Failure Modes and Effects Analysis

B2. Criticality and Maintainability Analysis

C. Operation and Maintenance Task Summary

D. Operation and Maintenance Task Analysis

D1. Personnel and Support Requirements

E,E1. Support Equipment and Training Material Description and Justification

E2. Unit Under Test and Justification Description

F. Facility Description and Justification

G. Skill Evaluation and Justification

H,H1. Support Items Identification

J. Transportability Engineering Characteristics.

The purpose of the LSAR is to provide a uniform, organized technical database that consolidates the engineering and logistics data necessary to identify the detailed logistic support requirements of a system. One use of the LSAR database should be to determine how the proposed logistic support system affects system RAM characteristics, including operational readiness.

DA PAM 700-50, *Integrated Logistic Support: Developmental Supportability Test and Evaluation Guide*, (Ref. 22) provides a methodology used to perform the evaluation of supportability issues. A logistics demonstration (LD) is a test or series of tests designed to demonstrate that all logistics and requirements have been satisfied. An LD should be performed to evaluate and validate ground support equipment as well as other supportability requirements. The LD is capable of providing data to evaluate the design of materiel with respect to qualitative maintainability aspects, e.g., accessibility, ease of maintenance, use of modular components, incorporation of test points, human factors, safety, and elimination of unnecessary preventive maintenance checks and services. All tasks should be performed at the operator or crew and organizational levels (unit) maintenance and selected tasks at the direct support and general support levels. The LD investigates personnel skill requirements, adequacy of training programs and materials, and the adequacy of equipment manuals. The LD also investigates the allocation of tasks to the appropriate maintenance levels based on personnel skills, maintenance capability, and maintenance allocation charts (MAC), fault diagnosis procedures, and testability of equipment and software. The results of the LD validate and update LSAR data.

10-11 BATTLE DAMAGE ASSESSMENT AND REPAIR (BDAR)

New tactical air vehicles are normally designed to be ballistically survivable on the modern battlefield by incorporating active and passive signature reduction and ballistic tolerance features. A large percentage of these air vehicles return from combat missions with various levels of combat damage. Maximum air vehicle availability is essential during surge operations; therefore, quick assessment and repair of the damage are necessary. To assess damage and determine reusable parts and components, some additional tools and equipment are required, as well as additional training for aviation unit , direct and general support level maintenance personnel.

The types of threats confronting the US Army rotorcraft in combat include kinetic energy projectiles, explosive projectiles, and air-to-air and surface-to-air missiles with explosive warheads. In addition to the threats the rotorcraft might encounter in flight, they are exposed to damage by bombs and artillery while on the ground. Threat studies and tests have shown that modern rotorcraft are highly survivable against the kinetic energy hits, moderately survivable against one or two small explosive hits, and minimally survivable against a large explosive or single air-to-air or surface-to-air missile hit. Being the most survivable of the threats, kinetic energy hits cause most of the damage that maintenance personnel will encounter. Some of these projectiles are the armor-piercing incendiary (API) type and contain a thermally active nose filler. Upon impact, this filler is activated as the projectile penetrates the exterior of the target. This gives the projectile a fire-starting capability in the presence of flammable materials. Damage mechanisms for the explosive threats include fragments, blast, overpressure, fire, and other secondary damage. A BDAR program should be established to provide an expeditious means of combat damage assessment for deferment or repair. The BDAR program should include special techniques, tools, equipment, and procedures to be used by aviation units under combat conditions. The primary function is to provide quick-fix material and techniques to increase air vehicle availability under an intense combat environment. The program should be composed of required hardware and documentation to provide the capability to inspect, assess, and repair the air vehicle. Support documentation includes inspection procedures, damage assessment criteria, serviceability criteria, expedient repair procedures, cannibalization techniques, and assessment and repair handbooks. Hardware includes damage assessment aids (such as die penetrant kits, micrometers, etc.), repair tools, ground support equipment, and repair material.

The assessment process includes evaluating the extent of damage sustained and determining whether deferment is feasible. Scheduled and unscheduled maintenance and minor battle damage, except for necessary lubrication, servicing, and preoperational checks, may be deferred. Unscheduled maintenance, such as the repair of systems and subsystems that have adequate redundancy or are not critical to mission accomplishment, can be deferred if safety of flight is not significantly degraded. Relaxed inspection criteria for repair and air vehicle performance should also be defined. For example, the number of broken strands in flight control cables, leak rates of hydraulic systems, and oil consumption rates of engines and gearboxes should be redefined.

The BDAR process also includes procedures to perform rapid battle damage repair where necessary within the constraints imposed by time, manpower, material, and operational requirements. The primary purpose of rapid battle damage repair is to restore sufficient strength and serviceability to the air vehicle to permit it to fly additional operational missions or to permit partial mission capability. Demonstrations of typical repairs should be made to determine whether the structural integrity, time constraints, tools, and maintenance personnel meet defined requirements.

The types of structure and the material forms should be considered. Primary structures, such as beams, frames, longerons, and fittings, are essential to airworthiness because airworthiness of the entire airframe depends on the distribution of loads through the individual structural elements. When combat damage reduces the strength, stiffness, or stability of these elements, a decision on repair methods must be made. This critical decision should be based on a judgment of whether redistribution of the load may degrade flight safety or adversely affect flying qualities. Sheet stock and extruded materials that are not preformed are needed for most repairs. Typical materials used in modern air vehicles include aluminum, steel, titanium, magnesium, and composites. These materials may be worked and formed into airframe structures, such as brackets, ribs, bulkheads, extrusions, honeycombs, or sandwiched assemblies.

Consideration should also be given to the use of installed instrumentation and monitoring devices to make reusability decisions in the field after a combat incident or resulting crash. Possible devices include but are not limited to accelerometers; maximum g recorders; debris monitors; engine torque, temperature, and RPM monitors; and heat sensitive paint and paper indicators. Knowledge of these damage or crash parameters helps expedite deferment or repair assessment.

Measures used to quantify BDAR qualification may include time to repair (TTR) at each maintenance level and effectiveness of the repair, which is expressed as the number of life units the repair lasts.

10-12 CORROSION PREVENTION AND CONTROL PROGRAM

Air vehicle system and component reliability might be significantly reduced when introduced to a corrosive environment in any phase of the materiel life cycle. A corrosion prevention and control program should be established for aviation systems and implemented through a contractor-prepared corrosion prevention and control plan, contractor-prepared finish specifications, contractor-prepared, system-peculiar corrosion prevention maintenance procedures, and a Government/contractor corrosion prevention action team (CPAT). The program should be established in accordance with AR 750-59, *Army Corrosion Prevention and Control Program*, (Ref. 23) and MIL-STD-1568, *Materials and Processes for Corrosion Prevention and*

Control in Aerospace Weapons Systems, (Ref. 24) for Air Force applications.

The contractor should prepare a corrosion prevention and control plan, which describes the contractor's approach to corrosion prevention and control measures to be implemented to minimize or eliminate potential corrosion of the air vehicle system being procured. This includes installation of Government-furnished equipment (GFE) and contractor-designed associated ground equipment. The plan should include the establishment of a Government/contractor materials review to optimize material selection for a particular application prior to design configuration and fabrication of any part or component. The plan should also include establishment of a test program to determine qualification and verification of the effectiveness of corrosion protection.

The contractor should prepare a finish specification, which describes the specific corrosion protection finish or techniques to be used on the various substrates of all components and assemblies to protect them against corrosion in the environments to which they will be exposed. Information concerning this specification can be found in MIL-F-7179, *Finishes, Coatings, and Sealants for the Protection of Aerospace Weapons Systems*, (Ref. 25). Surface coating methods include using alloy materials that are chemically resistant to corrosion, covering with an impermeable surface coating so air and water cannot reach the coated surface, and coating with a material that will react with corroding substances more readily than the surface material being coated. Surface coating and corrosion resistance testing for compliance with requirements is usually conducted in conjunction with environmental stress testing and includes exposure to salt spray environments and temperature extreme variations.

The primary consideration in the design and construction of aviation systems is the ability of the design to comply with structural and operational requirements. In addition, aviation components are expected to perform reliably and to require minimum maintenance over a specified lifetime. Therefore, during the selection of suitable materials and appropriate processing methods to satisfy structural requirements, consideration must also be given to those materials, processing methods, and protective treatments that minimize the rate of material deterioration and that reduce service failures due to corrosion of parts and assemblies in service. Deterioration modes that contribute to service failures include but are not limited to pitting corrosion, galvanic corrosion, exfoliation corrosion, stress corrosion, corrosion fatigue, thermal embrittlement, weathering, and fungus growth. Throughout the entire design phase attention should be given to precautionary measurements in order to minimize deterioration of individual parts and assemblies as well as the entire system. Precautionary measures include proper selection of materials, limitations of design operation stresses, relief of residual stress levels, shot peening, heat treatments that reduce corrosion susceptibility, and protective coatings and finishes. Information concerning this topic can be found in ADS-13, *Air Vehicle Materials and Processes,* (Ref. 26).

The design of the system should prevent water leaking into or being driven into any part of the system interior, either on the ground or in flight. The air vehicle should satisfy the watertightness requirements of MIL-W-6729, *Watertightness of Aircraft, Testing, General Specification for,* (Ref. 27). Sealed floors with suitable drainage should be provided for cockpits and cargo compartments. Adequate ventilation should be provided in all areas to prevent moisture retention and buildup. Use of dissimilar metals in contact should be limited to applications in which similar metals cannot be used due to peculiar design requirements. The metals should be protected against galvanic corrosion by interposition of a material that reduces the overall electrochemical potential of the joint or by interposition of an insulating or corrosion-inhibiting material. Information concerning determination of the corrosion prevention requirements can be found in ADS-13 (Ref. 26).

The contractor should ensure that the electronic parts and components in aviation systems are protected from corrosion. Relevant information can be found in MIL-STD-1250, *Corrosion Prevention and Deterioration Control in Electronic Components and Assemblies*, (Ref. 28). Protective measures should be sufficient to maintain performance characteristics within specified limits both during and after exposure to moisture, high and low temperatures, corrosive gases, chemicals, and microbial attack. NAVMAT P 4855-2, *Design Guidelines for Prevention and Control of Avionics Corrosion*, (Ref. 29) describes some of the characteristics of the corrosive environment in which US Navy avionics systems and equipment are maintained and operated. Design methods used to prevent corrosion on electronic equipment include material selection, coatings, and environmental enclosures.

Adequate precautions should be taken during manufacturing operations to maintain the integrity of corrosion prevention measures and to prevent the introduction of corrosion or corrosive elements. Surfaces should be adequately cleaned prior to application of surface treatments and coatings. Information concerning cleaning of surfaces can be found in MIL-S-5002, *Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems*, (Ref. 30). Damage to any previously applied surface treatment or protective finish should be repaired. All parts and assemblies should be given adequate protection to prevent corrosion and physical damage during temporary or long-term storage and shipment.

The contractor should prepare system-peculiar corrosion control procedures that detail the maintenance procedures to be used by personnel in the unit, direct and general support, and depot repair levels. Maximum use should be made of TM 55-1500-344-23, *Aircraft Weapons Systems Cleaning and Corrosion Control*, (Ref. 31) and TM 55-1500-343-23, *Avionics Cleaning and Corrosion Prevention/Control*, (Ref. 32) The procedures should base corrosion inspections on calendar time rather than on flight hours, identify corrosion-prone areas, and establish corrosion limits that require replacement of parts, components, and assemblies.

A Government/contractor CPAT should be established to ensure that the goals of the corrosion prevention and control program are achieved. Periodic reviews of the facilities in which parts are fabricated, processed, assembled, and readied for shipment should be held. Discrepancies are documented and submitted to the PA for resolution.

10-13 STANDARDIZATION AND INTEROPERABILITY

The Joint Chiefs of Staff of the Department of Defense (DoD) have established five priority areas for standardization and interoperability. Three of these areas are primarily applicable to a particular US Army air vehicle system: cross-servicing of air vehicles; ammunition;

and battlefield surveillance, target designation, and acquisition systems.

10-13.1 STANDARDIZATION

DoD Directive (DoDD) 2010.6, *Standardization and Interoperability of Weapons Systems and Equipment Within the North Atlantic Treaty Organization (NATO),* (Ref. 33) defines standardization as the process by which member nations of NATO achieve the closest practicable cooperation among forces; the most efficient use of research, development, and production resources; and agree to adopt, on the broadest possible basis, the use of common or compatible operational, administrative, logistic, and technical procedures and criteria, tactical doctrine with corresponding organizational capability, and common, compatible, or interchangeable supplies, components, weapons, or equipment.

If required, standardization testing and analyses for cross-servicing of air vehicles; ammunition; and battlefield interoperability, logistics and electronic, are explained in Enclosure 2 of DoDD 2010.6. Although standardization of the three areas of cross-servicing of air vehicle; ammunition; and battlefield surveillance, target designation, and acquisition systems is a desired characteristic, interoperability is typically a required characteristic. Interoperability should be tested and demonstrated to ensure that, with reasonable modification of equipment and/or procedures, POL and ammunition may be exchanged between NATO nations. If required by the PA, other tests and analyses should be conducted to ensure that the forces of one NATO nation can service targets acquired and designated by the forces of another nation and can acquire and designate targets for the other nation, and that each nation can electronically provide and accept battlefield surveillance and surveillance, target designation, and acquisition systems should involve form, fit, and function testing of each system involved in these three areas. If applicable, petroleum, oils, and lubricant (POL) specifications should be compatible, and receptacles for those items should be standardized. Also, if applicable, other items, such as ammunition and battlefield surveillance, target designations, and acquisition systems, should be demonstrated to be interchangeable without modification or loss of effectiveness.

10-13.2 INTEROPERABILITY

DoDD 2010.6 (Ref. 33) defines interoperability as the ability of systems, units, or forces to provide to (or accept from) other systems, units, or forces the services necessary for those elements to operate effectively together. Two types of

intelligence data to or from the forces of other NATO nations.

10-14 SHIP-BASED OPERATION COMPATIBILITY

US Army rotorcraft that are able to launch from, recover to, and operate around US Navy ships provide increased strategic and tactical mobility. The ability to use US Navy ships as intermediate refueling and rest stops allows self-deployment of Army rotorcraft for greater distances and partially eliminates the need for US Air Force transport aircraft. While in an area of operations, operations from Navy ships allow longer time-on-station.

Testing and analysis to demonstrate shipboard compatibility involves surveys of the facilities of the ship, demonstration of ability to operate and maintain rotorcraft on a particular ship, and testing to determine the dynamic interface of rotorcraft with the ship electromagnetic compatibility and vulnerability, water intrusion capability, and corrosion control.

10-14.1 SHIP FACILITIES

NAVAIRENGCEN Report NAEC-ENG-7576, *Shipboard Aviation Facilities Resume*, (Ref. 34) describes the physical characteristics and available logistics support and services available on various classes of US Navy ships. Each group of ships may have one or more subgroups (guided missile frigates (FFG) 456 through 467, for example) according to equipment installed. Landing and vertical replenishment (VERTREP) spot dimensions, clearance, deck structure, safety items, and mooring aids are described. Also included is a matrix of available electrical capabilities, petroleum, oils, and lubricants, pressurized air, freshwater, rotorcraft in-flight refueling capabilities, visual landing and navigation aids, hangars, and other equipment and facilities necessary to support, service, and maintain a rotorcraft or other aircraft logistically. Locations for these available services are depicted in platform and profile views of the landing areas.

Limitations on use of available ship services for each class of ships should be established. If required by the PA, limitations should be evaluated by demonstration to determine the impact of operating US Army air vehicles for extended periods of time using only facilities and supplies normally carried onboard the ship. Necessary support that must be brought onboard by the US Army to support the air vehicle should be identified. Examples are ground handling equipment, POL not common to the US Navy, and rotor blade racks or folding supports.

10-14.2 DYNAMIC INTERFACE

Selected US Navy ships possess air-capable ship certification, which signifys that these ships have been formally inspected and certified to be able to provide proper, adequate, and safe aviation facilities and to meet the applicable requirements of *Air-Capable Ships Aviation Bulletin* Number 1G (Ref. 35). However, without certification for US Army rotorcraft to operate on those ships, NWP 42G, *Shipboard Helicopter Operating Procedures*, (Ref. 36) requires a waiver from the Fleet Commander-in-Chief citing specific levels of operation, classes of services provided, types of rotorcraft, operating procedures, missions, geographic locations, times, etc.

Consequently, formal certification of US Army rotorcraft for operation from air-capable ships should involve testing to establish certain specific parameters of subpar. 10-14.1. Dynamics interface testing, commonly referred to as shipboard compatibility testing, should be conducted to establish compatibility and limitations for shipboard operations. Testing should be conducted to determine operating limitations for wind speed and direction, ship roll and pitch, and support equipment. Rotorcraft control response and path control accuracy during shipboard landings and takeoffs should be determined and used to established operating limits. This testing should establish the ship wake effects on the rotorcraft, which are used to establish launch and recovery limitations and procedures.

Level I operations involve day and night operations in instrument meteorological conditions (IMC), Level II operations involve day and night operations in visual meteorological conditions (VMC), and Level III operations involve day only VMC operations. For each type of Army rotorcraft seeking certification, these limitations should be established and characterized on charts depicting launch and recovery wind limitations (also called approach envelopes). Classes of facilities required to support aviation operations are covered in NWP 42G (Ref. 36).

Other operational procedures that should be demonstrated are limitations for ship roll and pitch during launch and recovery, acceptable relative wind velocity and direction relative to the heading of the ship, and restrictions on operation in the presence of shipborne electronic emitters. If different limitations are imposed due to differing rotorcraft gross weights, these limitations should also be established. These demonstrated values, limitations, and restrictions should be documented on the charts depicting launch and recovery wind limitations. A sample of this chart is shown on Fig. 10-4. Launch and recovery wind limitations charts provide the ship approach envelope and are based on ship wake effects and other limitations determined during dynamic interface testing.

For rotorcraft with rotor brakes, limitations for engagement and disengagement of rotors should be established when these limitations are more stringent than those in the operator's manual for the rotorcraft. For rotorcraft that cannot operate main engines without rotors turning, limitations for engine start and stop should be established when they differ from those in the operator's manual.

If rotor brakes are installed and/or rotor folding is required, the operation of the rotor brake should be demonstrated, and wind-over-the-deck limits for rotor blade folding should be established.

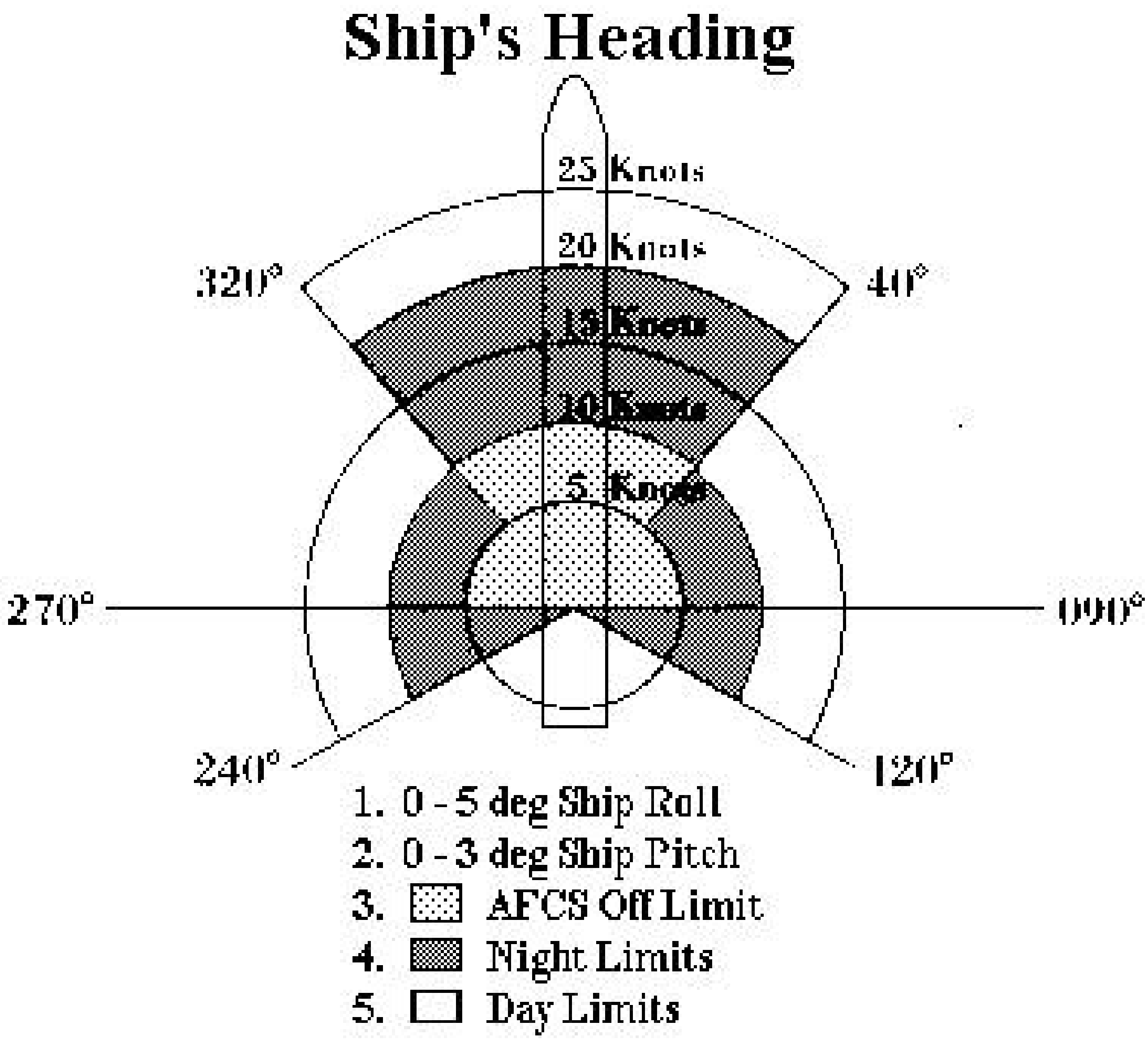
Location of tie-down points on the rotorcraft should be provided as well as the preferred orientation of tie-downs, e.g., 45-deg angles with deck. Rotor engagement/disengagement limitations, blade folding limitations, and tie-down points should be documented in charts separate from the launch and recovery wind limitations charts.

10-15 GROUND SUPPORT EQUIPMENT

Ground support equipment (GSA) includes the equipment that is not part of the air vehicle or system but is required for operation and/or maintenance of the air vehicles. Typical ground support equipment includes but is not limited to ground auxiliary power units (APUs), special tools and test equipment, hydraulic and pneudraulic test stands, boresight equipment, and automatic test equipment (ATE). This equipment also requires preventive and corrective maintenance. Therefore, excessive numbers or quantities of support equipment items increase unit maintenance personnel requirements. The GSE should satisfy MANPRINT and safety requirements. Also health hazards should be identified and eliminated. For additional information and guidance, see MIL-HDBK-470 (Ref. 6). Typical objectives in the GSE area are to

1. Minimize maintenance downtime by designing for rapid and positive identification of parts, test points, and connections.

2. Minimize maintenance downtime by designing for rapid and positive calibration, adjustment, servicing, and testing.



AFCS = Automatic Flight Control System

Degree markings on figure are wind directions relative to aircraft's nose when aligned with ship's lineup line.

Figure 10-4. Launch and Recovery Wind Limitations (Adopted from Ref. 36)

3. Minimize the complexity of maintenance by designing for minimum maintenance tools, accessories, and equipment.

4. Eliminate the need for special tools to perform unit maintenance.

During maintainability demonstrations, support equipment determined to be inadequate should be reported using the PA-approved data collection, analysis, and corrective action system. For additional information and guidance, see MIL-HDBK-471 (Ref. 5).

10-15.1 SPECIAL TOOLS AND TEST EQUIPMENT

Special tools and test equipment are defined as tools or test equipment that are system or equipment peculiar. As mentioned in par. 10-15, the maintainability design goal is elimination of special tools and test equipment at the unit maintenance level. Testing and measurements for special tools and test equipment should be conducted as part of the logistic demonstration as discussed in par. 10-10. Test equipment and tools required for corrective and preventive maintenance at each maintenance level should be recorded. Use of special tools and test equipment at these levels should be documented and reported using the PA-approved data collection, analysis and corrective action system. The PA should establish specific test requirements, passing criteria, and MTTR penalties for use of special tools or test equipment as required.

10-15.2 BORESIGHT EQUIPMENT

Boresighting is defined as alignment of the sighting subsystems of the weapon with the predicted impact points of the munition within acceptable limits. Normally, this boresight process is accomplished using mechanical fixtures, electronic boresight mechanisms, or a combination of the two.

The boresight equipment for an aviation system should be used with appropriate procedures to demonstrate elapsed time and maintenance man-hours required to boresight all weapons systems. Boresight retention should be periodically rechecked to determine whether significant amounts of preventive maintenance downtime are involved. In addition, boresight retention should be rechecked after weapons firing. Results of these demonstrations should be documented using the PA-approved data collection, analysis, and corrective action system.

Calibration intervals for the boresight equipment should be established by the contractor. Demonstration of calibration procedures, calibration intervals, and resistance to damage should be the subject of calibration validation for boresight equipment requiring calibration.

10-15.3 GROUND POWER UNITS

Equipment in this category includes ground APUs and pneudraulic starters. Environmental conditions that require use of ground power units, e.g., temperatures below a specified value, should be established by the contractor. These ground power units should be subjected to functional tests under the environmental conditions expected for the air vehicle. These functional tests should verify that electrical and pneudraulic power outputs are sufficient to support air vehicle operation and maintenance needs in all of the environmental conditions specified.

Additionally, reliability and maintainability tests should be conducted to ensure that operating and support (O&S) costs and operational availability for the ground power units are within acceptable ranges. Excessive manpower or parts requirements or low availability for ground power units can reduce operational readiness

(OR) rates due to increased the total administrative and logistic delay time (TALDT).

Mobility of ground power units should also be evaluated. Strategic mobility for air vehicles requires that all necessary support equipment be equally deployable. Tactical mobility also requires that support equipment be movable by unit equipment. Strategic or tactical mobility limitations should be identified for ground power units.

10-15.4 AUTOMATIC TEST EQUIPMENT (ATE)

Air vehicle systems supported by ATE are considered units under test (UUT). The purpose of ATE testing is to verify ATE performance and diagnostic fault isolation on each UUT to the levels specified. Systems should be designed to minimize the requirement for use of external ATE. If ATE is required, the designer should make maximum use of existing ATE. Qualification of ATE and associated test program sets (TPS) includes software as well as hardware.

10-16 TIE-DOWNS AND MOORINGS

Discussion of shipboard tie-down qualification is provided in par. 10-14. However, additional qualification requirements exist for the air vehicle. Prior to dynamic component qualification test on a ground test vehicle or tied down rotorcraft, strength of tie-down points and moorings should be demonstrated. Qualification of tie-down points for transportability is discussed in par. 10-8.

Other qualification requirements involve tie-down points for internal cargo. Proper operation of all tie-down fittings and devices should be demonstrated. Using representative demonstration cargoes, the demonstration should be performed in accordance with procedures in the operator's manual. Emphasis should be placed on accessibility and ease of operation of tie-down provisions.

Provisions for tying down ma in and tail rotor blades should be demonstrated. If a main rotor gust lock is provided, it should be demonstrated under environmental conditions specified by the PA. If tail or main landing gear wheel locks are part of the design, these should also be demonstrated under the same environmental conditions.

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ACRONYMS AND ABBREVIATIONS

AC	=	air vehicle contractor
AFCS	=	automatic flight control system
ALDT	=	administrative and logistic delay time
AMC	=	air mobility command
API	=	armor-piercing incendiary
APU	=	auxiliary power unit
AQS	=	airworthiness qualification specification
ATE	=	automatic test equipment
BDAR	=	battle damage assessment and repairs
BIT	=	built-in test
CA	=	criticality analysis
CMT	=	corrective maintenance time
CONUS	=	continental united states
CPAT	=	corrosion prevention action team
CRAF	=	civil reserve air fleet
CS	=	combat support
CSS	=	combat service support
DoD	=	department of defense
DoDD	-	department of defense directive
DS	=	direct support
DT/OT	=	developmental/operational test
ESS	=	environmental stress screening
f	=	failure rate
g	=	acceleration as a result of gravity
FD/SC	=	failure definition/scoring criteria
FMECA	=	failure mode, effects, and criticality analysis
FRACAS	=	failure reporting analysis and corrective action system
GFE	=	ground support equipment
HFE	=	human factors engineering
HQDA	=	headquarters, department of the army
ILS	=	integrated logistic support
IMC	=	instrument meteorological conditions
IOT&E	=	initial operational test and evaluation
LD	=	logistics demonstration
LSA	=	logistics support analysis
LSAR	=	logistic support analysis record
NATO	=	north atlantic treaty organization
MAC	=	maintenance allocation charts
MANPRINT	=	manpower and personnel integration
MARC	=	manpower requirements criteria
MCTF	=	mean cycles to failure
MOP	=	measure of performance
MRBS	=	mean rounds between stoppage

MTBCF	=	mean time between critical failures
MTBF	=	mean time between failure
MTBUMA	=	mean time between scheduled maintenance actions
MTMC	=	military traffic management command
O&S	=	operating and support
OCONUS	=	outside conus
OMS/MP	=	operational mode summary/mission profile
OR	=	operational readiness
OT	=	operating time
OT&E	=	operational test and evaluation
PA	=	procuring activity
POL	=	petroleum, oils, and lubricant
PRAT	=	production reliability acceptance test
PRST	=	probability ratio sequential test
RAM	=	reliability, availability, and maintainability
RCM	=	reliability centered maintenance
RGT	=	reliability growth test
RIW	=	reliability improvement warranty
RPM	=	revolutions per minute
RQT	=	reliability qualification
RSI	=	rationalization, standardization, and interoperability
SME	=	subject matter experts
ST	=	standby time
TALDT	=	total administrative and logistics delay time
TBO	=	time between overhaul
TCM	=	total corrective maintenance downtime
TMDE	=	test measurement and diagnostic equipment
TO&E	=	tables of organization and equipment
TPM	=	total preventive maintenance downtime
TPS	=	test program sets
TT	=	technical test
TTR	=	time to repair
MA	=	unscheduled maintenance action
UUT	=	units under test
VERTREP	=	landing and vertical replenishment
VMC	=	visual meteorological conditions
VV&A	=	validation, verification, and accreditation